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Data on frequencies actually used by Navy ships and communications stations is used to compare indicators of quality for those frequencies predicted by DNC-14 to propagate well with those predicted to propagate more poorly. The results indicate the extent to which attention paid to DNC-14 predictions can be expected to pay off in reduction of effort required to maintain circuit continuity.

CRC-278

CORRELATION OF DNC-14 FREQUENCY PREDICTIONS WITH OPERATIONAL EXPERIENCE

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INTRODUCTION

DNC-14[1] (reference 1) is published annually by the Navy to provide circuit controllers with guidelines for selecting frequencies by displaying predictions of:

- Maximum usable frequency (MUF) – the highest frequency expected to propagate 50 percent of the days in a given month.

- Frequency of optimum traffic (FOT) – the highest frequency expected to propagate 90 percent of the days in a given month.

A third parameter, the lowest usable frequency (LUF)–indicating the lower threshold for excessive signal attenuation–was also provided at one time. But it has since been deleted from the series because it was considered to be less useful than MUF and FOT.

These parameters are produced from a computer simulation model. The model uses past observations of diurnal and seasonal variations in the heights of various ionospheric layers that reflect high-frequency radio waves and propagation geometry to predict future propagation by hour of day and distance. The computer printouts of FOT and MUF for various region-to-region propagation paths centered on major Navy communications stations (CommStas) are then provided to circuit controllers along with the guidance that the search for usable frequencies should proceed by:

- First trying frequencies close to FOT.
- Then trying frequencies above FOT but below MUF.
- Finally, those below FOT in descending order.

The guidelines also recommend that FOT and MUF be plotted on a graph so that daily trends in frequency propagation will be apparent, and circuit controllers can anticipate when frequencies being used will begin to deteriorate.

Operators who regularly use DNC-14 predictions feel that these guidelines greatly ease their efforts to maintain circuit continuity. However, because the MUF-FOT predictions are monthly medians based on past observations, they are not completely accurate. Frequencies between FOT and MUF will not always propagate well; nor will those above MUF always be poor. Moreover, all frequencies are affected by unmodeled variables such as local interference, poor antenna response, equipment limitations, and propagation disturbances resulting from solar flares and magnetic storms. Some operators therefore feel that DNC-14 predictions contribute little toward improving individual circuit performance; they prefer instead to rely on monitoring and experience.

To assess these conflicting views of the utility of DNC-14, this research contribution examines data on frequencies actually used by ships and CommStas to determine whether the best frequencies as predicted by DNC-14 are indeed significantly better, and to estimate the possible impact of the preferential use of the recommended frequencies on operational performance.

---

[1] The name of the publication has been changed to NTP-6 SUPP-1 since this report was written, but the guidelines are the same.

RESULTS AND OPERATIONAL IMPLICATIONS

The analysis reported here examined data from periods when LUF-FOT and FOT-MUF predictions were provided and when all three parameters were available. For each data set, the frequencies copied were typified as being inside or outside the DNC-14 envelope—that is, the band or bands defined by the available parameters. In addition, for those cases in which LUF and FOT were given, frequencies were typified as being copied during a "no-envelope" condition whenever LUF was predicted to be higher than FOT (indicating that no frequency was expected to propagate well). The frequencies copied were then analyzed and compared in terms of performance indexes, durability of frequencies, and distribution of frequencies copied to produce results in three areas.

ANALYTICAL RESULTS

Performance Indexes

The two performance indexes used were shift and outage rates. Shift rates indicate how often the operator had to shift frequencies to maintain circuit continuity. Outage rates indicate the proportion of the total time (during which given frequencies were being copied) that the circuit was logged as being "out" for frequency-related causes. In terms of these indexes, the analysis shows that:

- *Shift rates for frequencies within the FOT-MUF and LUF-FOT frequency bands were about equal; for frequencies outside the LUF-MUF envelope, shift rates were consistently greater.* As a matter of fact, shift rates for frequencies outside the LUF-MUF envelope were from 1.85 to 2.17 times greater than those for frequencies inside the LUF-MUF envelope.

- *For those cases where LUF was provided and predicted to exceed FOT, the shift rate for frequencies outside the DNC-14 envelope was close to that for frequencies copied during such no-envelope periods.* When both LUF and FOT are given in a DNC-14 prediction, there may be periods when LUF is greater (that is, "no-envelope"), indicating that no frequency is expected to propagate well. For two data sets for which LUF-FOT predictions were available, the average shift rates during such no-envelope periods (normally occurring during the evening transition periods) were 0.775 and 0.279 shift per hour, compared with 0.579 and 0.269 shift per hour for frequencies outside the LUF-FOT band.

- *In five of the 10 data sets analyzed, outage rates for frequencies copied outside the DNC-14 envelope considered were from 40 to 80 percent higher than those for frequencies within the envelope.* Outage rates for frequencies outside the LUF-MUF envelope were found to be nearly 80 percent greater than those for either the LUF-FOT or FOT-MUF bands. The overall outage rate for frequencies in the LUF-FOT band was only 20 percent higher than that for frequencies in the FOT-MUF band. This indicates that frequencies below LUF and above MUF are inferior to those predicted to be usable by DNC-14.

- *In two of the 10 data sets examined, outage rates were 30 percent less for frequencies outside the DNC-14 envelope.* In these two cases, frequencies exhibiting the lower outage rates were clearly above MUF.

• *Outage rates for frequencies copied during no-envelope periods were consistently higher than those for frequencies within an envelope—from 1.9 to 8.1 times greater.*

In addition to highlighting the utility of DNC-14, the data analyzed reveals differences between the ship/shore and shore/ship sides of full-period terminations and the degradation in performance caused by competition for frequencies. Specifically:

> • Outage rates for ship-to-shore circuits were 1.5 to 4 times higher than for shore-to-ship circuits; in two of three cases, shift rates were higher on ship-to-shore circuits. These results are consistent with the fact that transmitting power and quality of equipment are usually greater on the shore side of a termination.
>
> • Shift and outage rates for ships on Yankee Station in the Gulf of Tonkin were twice those observed for ships in transit. Three major units terminated with NCS Guam had a average shift rate of 0.42 shift per hour during a period when most of their time was spent on Yankee Station. Overall shift rates for ships in transit, when they were relatively free of competition for frequencies from other terminated units, were below 0.23 shift per hour in six of seven cases. The average outage rate for the 3 Yankee Station units was 9.5 percent, compared with 5.0 percent for 7 units in transit.

Frequency Durability

To further analyze DNC-14's usefulness in anticipating changes in propagation conditions, the duration of frequencies after a change in predicted FOT or MUF moved a frequency from inside to outside the good frequency envelope were examined. This analysis shows that:

• *When a change in the LUF-MUF envelope results in a frequency in use being placed outside the envelope, that frequency should deteriorate within 2 hours.* In those cases where close adherence to DNC-14 predictions was observed, 14.3 percent of the frequencies approaching MUF were shifted immediately, 78 percent within one hour, and all within 2 hours. Similarly, more than 95 percent of the frequencies approaching LUF were shifted within 2 hours after DNC-14 predicted they would be below LUF.

• *But for some samples, frequencies above the DNC-14-predicted MUF were copied for significant amounts of time.* In those samples, operators were able to copy frequencies above MUF for which only 50 percent were shifted within one hour, 70 percent within 2 hours, and 14 percent were still in use 4 or more hours after they were predicted to be above MUF.

Distribution of Frequencies Copied

Finally, estimates were made of the distribution of frequency-hours a ship spent within the MUF-LUF envelope. These results suggested two characteristics of DNC-14 predictions:

• *About 80 percent of the frequency-hours for each unit sampled fell within the LUF-MUF envelope, including periods when there was no LUF-FOT envelope.* Although actual LUF-MUF results could be computed for those cases where all three parameters were available, data from other sampling periods was coded so that a rough assumption about the missing third parameter could produce an estimate of the total time within the LUF-MUF envelope. For the three samples in which the LUF-MUF envelope was available, ships copied frequencies inside the envelope an

average of 87 percent of the time. For the remaining samples, ships were estimated to have used those frequencies 75 to 85 percent of the time.

- *Presenting a single DNC-14 band with either MUF-FOT or FOT-LUF parameters seems to bias an operator's choice of frequencies toward either band by about 10 percent.* When given both MUF and LUF, operators used frequencies above MUF 8 percent of the time; within the FOT-MUF band 34 to 44 percent of the time; within the LUF-FOT band 40 to 50 percent of the time; and below LUF 8 percent of the time. By contrast, when operators were given only FOT-MUF information, nearly 60 percent of the frequency-hours fell above FOT; and when they were given only LUF-FOT information, nearly 67 percent of the frequency-hours were below FOT.

OPERATIONAL IMPLICATIONS

General Conclusions

The results presented in this report compare shift and outage rates within a DNC-14 band with those outside the band. The operational impact of these results is that shift rates can be reduced 50 percent and outage rates 40 to 80 percent by following DNC-14 recommendations. When only two parameters were given, differences in shift rates were less consistent, and outage rates inside and outside the band were nearly equal.

Results from the different data sets, however, agree with the basic DNC-14 assumption that there is an operationally superior frequency region near FOT; outage and shift rates in this region are half those outside the region. During no-envelope periods, when the LUF-FOT band disappears and nearly all frequencies should be poor, outage rates are 2 to 8 times higher. Shift rates, however, are between those observed within and outside the DNC-14 envelope.

Comprehensive analyses of diurnal variations in shift and outage rates and the distribution of frequencies used about the DNC-14 curves have not been attempted. But the findings that nearly 80 percent of actual frequency use falls within the LUF-MUF envelope and that most frequencies are shifted within a relatively short time about the MUF or LUF curves show that DNC-14 is a reasonably good predictor of diurnal changes in frequency propagation.

The relationship of the DNC-14 parameters to the actual distribution of frequencies copied in some cases characterizes the frequency distribution very well. For example, in figure 5, FOT coincides with the distribution peak for all hours of the day, while MUF and LUF are nearly perfect cutoffs for the monotonically decreasing distribution above and below FOT.

However, that DNC-14 does not always predict the maximum usable frequency on any given day is amply demonstrated by the data from March 1971, for which the FOT-MUF predictions appeared to be low, and by the data from the Newport/Key West test, for which the frequencies used were above MUF 23 percent of the time. It is probably such exceptions that generate negative attitudes toward use of DNC-14.

Conclusions

The results, then, yield a profile of the nature of the contributions to operational performance to be expected from use of DNC-14 (NTP-6) predictions:

• *Attention paid to DNC-14 predictions can pay off in operational improvements.* That outage and shift rates were, in nearly all cases, found to be greater outside the DNC-14 envelope considered (LUF-FOT, LUF-MUF, and FOT-MUF) is consistent with the assumption that there is an operationally superior frequency region near FOT. The quantitative differences indicate that substantial reduction in shift and outage rates can be expected by following the guidelines.

• *Plots of DNC-14 parameters by hour can be of value in enabling controllers to anticipate when deterioration might occur.* Most frequencies in use deteriorated within 2 hours when changes in the DNC-14 predictions placed them into a band for which inferior propagation was to be expected; this shows that DNC-14 predictions can be used to anticipate and prepare for deterioration in quality.

• *DNC-14 predictions cannot be expected to be 100 percent reliable, and exceptions will occur.* Such exceptions should not be used as grounds for disparaging the general utility of the predictions. In some cases, frequencies above MUF were superior in terms of durability and shift and outage rates attained, demonstrating the statistical nature of the predictions and showing that DNC-14 will not always be completely accurate. Such exceptions to the predictions should not be treated as evidence of their lack of utility. In fact, the presence of good operating frequencies above MUF can be expected about half the time, by definition.

Recommendation

Since use of the predictions tends to bias the operator's selection of frequencies, and since above-the-MUF exceptions to the predictions can be expected to be a common occurrence, these conclusions suggest that utility to the operator and confidence in the predictions might be enhanced by revising the guidance on use of the series (now NTP-6) to read:

> "For the best circuit performance and the most reliable propagation, circuit operating frequencies should be selected in the order of preference: (1) authorized frequencies within plus or minus 10 percent of the FOT; (2) frequencies from within the predicted MUF-FOT band, remaining as close to the FOT as possible; (3) frequencies more than 10 percent below the FOT, in descending order. In this selection scheme, the MUF should not be treated as an absolute cut-off, because there will often be frequencies above the MUF that will provide for superior reception."

DATA SOURCES AND METHODOLOGY

Data for the analysis consisted mainly of daily full-period termination frequency logs on which frequency shifts and outages were recorded on charts of the DNC-14 predictions. Such data was obtained from 4 major units during 1969-1971 under the conditions shown in table 1. Some additional data was obtained from frequency and outage logs maintained by terminated units operating off the Atlantic Coast during the Newport/Key West test (April and May 1972). This data has been considered separately, however, because no frequency chart was maintained during the test period.

TABLE 1

DATA SOURCES

Ship	General location	Period sampled	Terminating CommSta	Send/receive
Annapolis	Indian Ocean	16 Apr-4 May 69	NCS Asmara	Receive
Oklahoma City	South China Sea East China Sea Sea of Japan	15-31 Jul 69 16-29 Jul 69	NCS Guam NCS Guam	Send Receive
Oklahoma City	East China Sea South China Sea Philippine Sea	18 Nov-18 Dec 69	NCS Guam	Send/receive
Oklahoma City	South China Sea	1-31 Jan 70	NCS Guam	Receive
Constellation	South China Sea	1-31 Jan 70	NCS Guam	Receive
Ranger	South China Sea	1-31 Jan 70	NCS Guam	Receive
Oklahoma City	South China Sea East China Sea Sea of Japan	16 Mar-14 Apr 71	NCS Guam	Send/receive

To set the geography for this data, the regions transited by each of the terminated units listed in table 1 and the relative locations of communications stations with which they were terminated are shown in appendix A.

Table 2 gives the number of frequency-hours available from the data taken during the sampling periods in table 1, and lists the DNC-14 parameters available to each participating unit. The differences in these parameters reflect changes that the DNC-14 format has undergone since 1969, as explained briefly in appendix B. The three-parameter charts (LUF, FOT, and MUF) used during the January 1970 test (see table 2 and figure 1) were distributed by the Director of Naval Communications in the format shown in appendix B as part of a special test of computer-generated graphics.

To further illustrate the nature of the data used, typical frequency plots for the different test periods are shown in figures 1 and 2 with the appropriate DNC-14 prediction envelope superimposed. Such plots show immediately when a frequency actually used was predicted to be good. In the examples shown, Oklahoma City seems to have copied frequencies close to FOT most of the time on the plot displayed in figure 1, but used frequencies above MUF more than 25 percent of the time in the case of the frequency plot of figure 2A. Assuming that the frequencies copied were

TABLE 2

FREQUENCY-HOURS AND DNC-14 BANDS USED IN ANALYSIS

Termination (to/from)	Period sampled	Frequency-hours	DNC-14 parameters
Annapolis/NCS Asmara	16 Apr-4 May 69	473.5	LUF-FOT
Oklahoma City/NCS Guam	16-29 Jul 69	666.0	LUF-FOT
NCS Guam/Oklahoma City	15-31 Jul 69	807.0	LUF-FOT
Oklahoma City/NCS Guam	18 Nov-18 Dec 69	1466.0	LUF-FOT
NCS Guam/Oklahoma City	18 Nov-18 Dec 69	1450.0	LUF-FOT
Oklahoma City/NCS Guam	1-31 Jan 70	922.3	LUF-FOT-MUF
Constellation/NCS Guam	1-31 Jan 70	1443.7	LUF-FOT-MUF
Ranger/NCS Guam	1-31 Jan 70	1019.4	LUF-FOT-MUF
Oklahoma City/NCS Guam	16 Mar-14 Apr 71	1660.3	FOT-MUF
NCS Guam/Oklahoma City	16 Mar-14 Apr 71	1245.5	FOT-MUF
Participating terminated units and communications stations for Newport/Key West test	Mar-Jun 72	1233	MUF
	Total frequency-hours = 12,386.7		

indeed the best available at the time, data such as this could lead to conflicting conclusions as to the utility of DNC-14. MUF, however, is calculated from past observations. Rather than being a sharp cutoff above which all frequencies are poor, it simply indicates the frequencies that will not propagate a significant percentage of the time. FOT and MUF, therefore, are guidelines to what the actual frequency propagation curve will look like on any given day.

Instead of focusing on the distribution of frequencies about LUF, FOT, and MUF, then, the more pertinent question is whether frequencies within the MUF-FOT or FOT-LUF envelopes exhibit characteristics that would make them operationally preferable. If they do, attention to the predictions will enhance operations even though the predictor cannot always be relied upon to isolate the "best frequencies."

Accordingly, the thrust of this analysis was to compare frequencies within the FOT-MUF and LUF-FOT bands—that is, those predicted to be operationally preferable—with the frequencies outside the envelopes in terms of their operational characteristics. This was done by determining whether a frequency at any time was within the appropriate DNC-14 envelope, outside the envelope, or in a no-envelope period. The total time that frequencies in these categories were copied was then extracted from the data, and outages were examined to quantify two indexes of performance.

Shift Rates

To maintain circuit continuity, it is necessary to shift from one frequency to another when a frequency being copied begins to deteriorate. When these shifts (which show up as stair-steps in figures 1 and 2) are classified as occurring within the LUF-FOT or FOT-MUF bands, outside the LUF-MUF envelope, or during the no-envelope period, a shift rate can be computed as the ratio:

$$SR(A) = \frac{\text{Number of shifts away from type A frequencies}}{\text{Total time type A frequencies were copied}}, \tag{1}$$

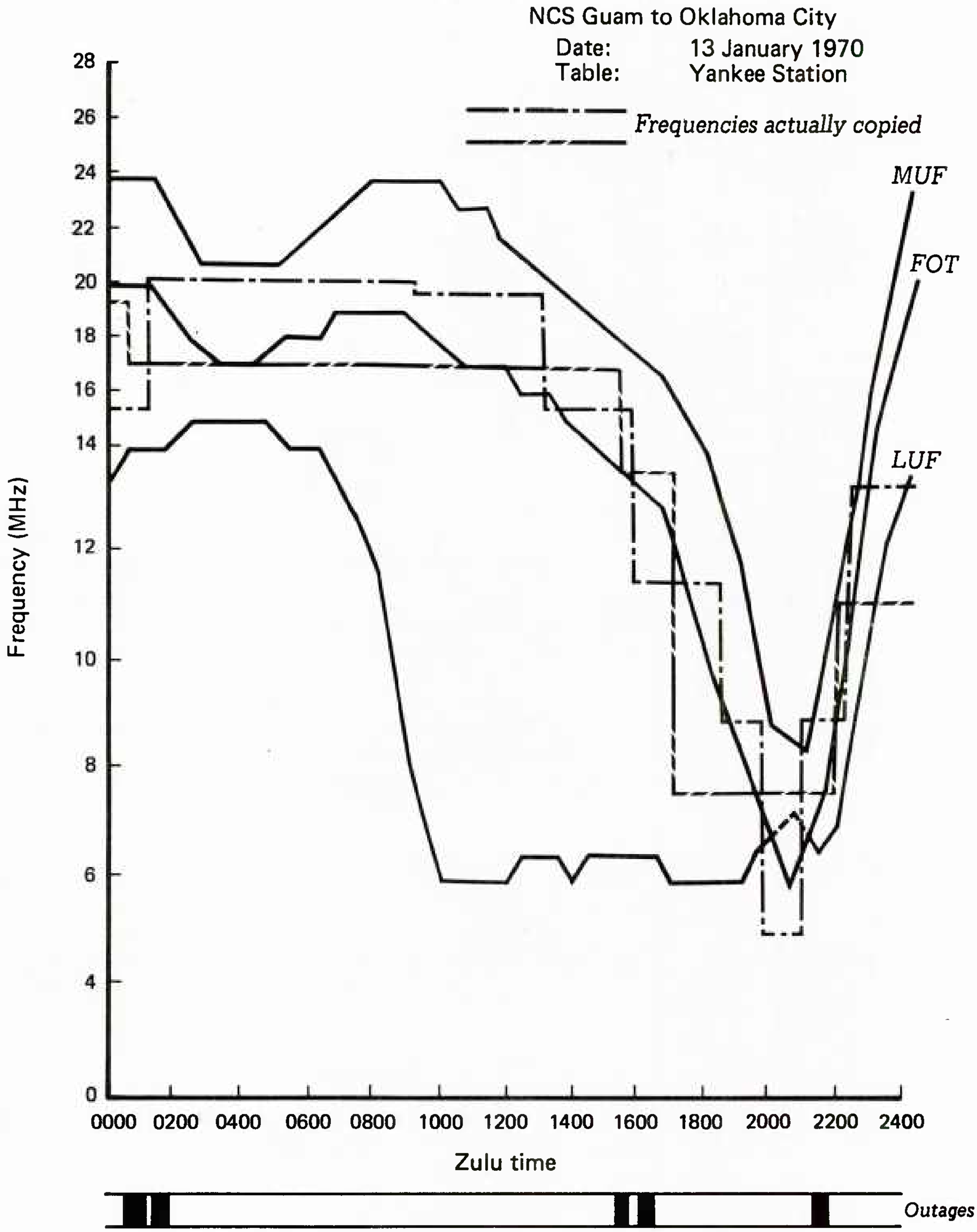


FIG. 1: EXAMPLE OF DNC-14 COMPUTER-GENERATED GRAPH OF MUF, FOT, AND LUF

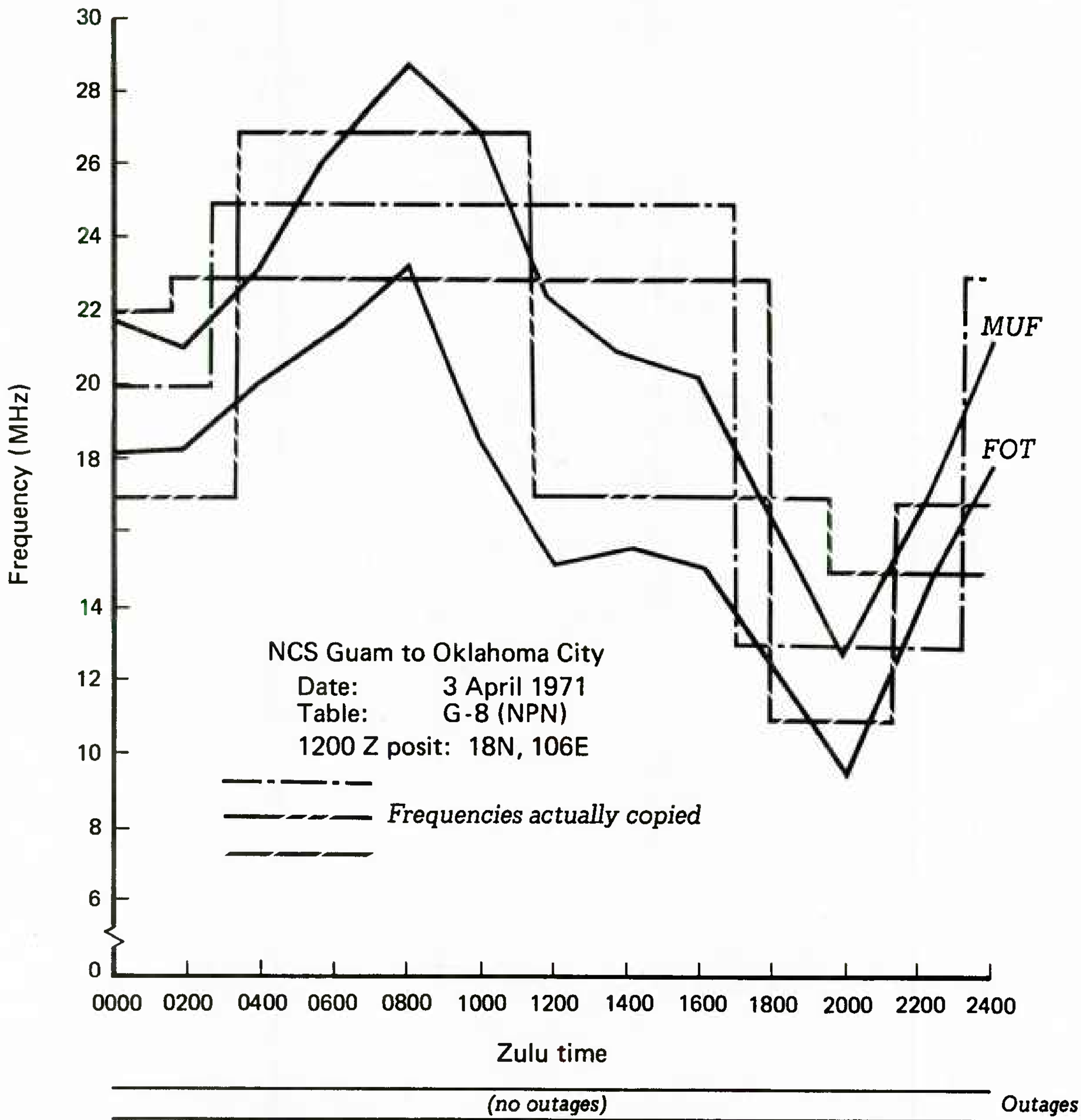


FIG. 2A: EXAMPLE OF DNC-14 FOT-MUF PREDICTION

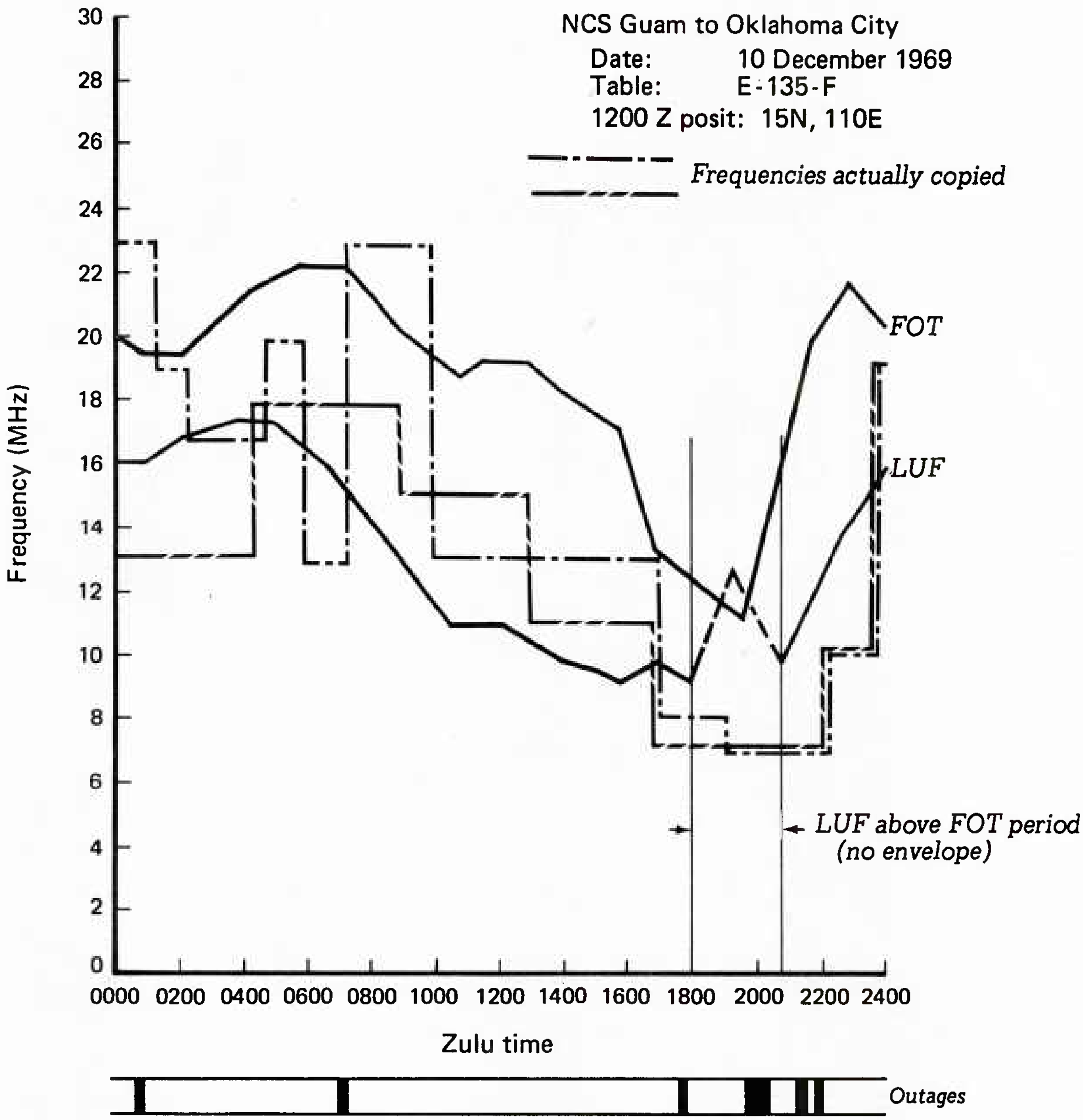


FIG. 2B: EXAMPLE OF DNC-14 LUF-FOT PREDICTION

where A is a variable denoting within, outside, or no-envelope. Since the monitoring of frequencies and the making of shifts are the circuit controller's most frustrating and time-consuming tasks, the shift rate serves as a good indicator of the amount of effort required to maintain circuit continuity.

Outage Rates

Even with frequency diversity (copying more than one frequency) and constant monitoring by the controller, it is difficult to maintain circuit continuity. Frequencies will fade suddenly, undergo heavy interference, or otherwise deteriorate to the point that usable traffic cannot be passed or crypto synchronization is lost. Such outages were recorded as shown at the bottom of figures 1 and 2, and their durations were extracted to compute outage rates as the ratio:

$$OR(A) = \frac{\sum_i T_i \cdot N(A)}{T(A)}, \tag{2}$$

where T_i = duration of the i^{th} outage;

$N(A)$ = number of frequencies of type A being copied during the outage;

and $T(A)$ = total time frequencies of type A were copied.

Equation 2 assumes that when an outage occurs, it affects both frequencies being copied. N(A) is thus an accounting factor allocating outage times to the frequency types being copied (within or outside the DNC-14 envelope) so that, for example, when one frequency copied is within the FOT-LUF band and the other is outside the FOT-MUF envelope, equation 2 allocates an outage to both frequency types.

These indexes were then extracted from the data and used to compare frequencies according to their relation to the DNC-14 predictions. While they are admittedly somewhat subjective in that they reflect the controller's opinion as to when to shift a frequency, gross differences in outage rates for frequencies of different types should represent operationally significant differences in their propagation characteristics.

Such comparisons are justified as measures of the accuracy of DNC-14 predictions by accepting two hypotheses.

The first hypothesis holds that in large samples for a region, the distribution of frequencies that propagated well will be stable relative to the DNC-14 predictions. DNC-14 FOT and MUF predictions are based on observed heights of ionospheric layers as they vary with time. Thus on a given day, an actual value may exhibit two kinds of deviations from the predicted average: height deviations (which occur when actual MUF and FOT are higher or lower than predicted) or time deviations (which occur when the changing heights of the ionospheric layers do not reach the DNC-14 predicted heights at the time predicted). This hypothesis simply asserts that such deviations, whatever they are, will, over a long time, cluster about some average value, so that observed trends in frequency duration and frequency shifts reflect actual HF propagation conditions.

According to the second hypothesis, once a frequency has been selected, it will be copied until it begins to deteriorate, or until another frequency good enough to warrant a shift is detected. Under this hypothesis, the majority of frequency shifts should occur near the time of change in MUF or LUF.

With these hypotheses, a good idea of the operational impact of using DNC-14 can be gained by observing the outage and shift rates inside and outside the bands defined by DNC-14 parameters.

To further examine how closely actual frequency selection matched DNC-14 predictions, and to determine what an operator can expect when a frequency being copied approaches predicted MUF or LUF, the distribution of frequencies copied over a large number of days was plotted whenever enough data covered a single DNC-14 prediction region and time interval. The distribution of frequency shifts around LUF, FOT, and MUF was analyzed for each available data set. This will show what LUF and MUF indicate with respect to the time a frequency will actually deteriorate, and how close the predicted LUF-FOT-MUF parameters approximate the actual frequencies copied.

ANALYSIS

Charts listing all three DNC-14 parameters—LUF, FOT, and MUF—were available only for the data taken from January 1971. The two parameters normally listed in DNC-14 publications were FOT and LUF in 1969 and FOT and MUF after 1970.

Using these parameters, four frequency envelopes were defined: LUF-FOT; FOT-MUF; outside LUF-MUF (excluding the no-LUF-FOT envelope); and no-LUF-FOT envelope. The last category was created because DNC-14 sometimes predicts LUF to lie above FOT during some hours of the day in some regions, indicating no frequency below FOT is expected to propagate well. Only a portion of the FOT-MUF band remains during this no-envelope period. Controllers then have only a very narrow region, if any, in which to select a good frequency.

Data collected during January 1970 was then grouped according to all four categories. For the data from March and April 1971, only two frequency regions—FOT-MUF and outside FOT-MUF—were defined. For data from April through December 1969, only three regions—LUF-FOT, outside LUF-FOT, and no-LUF-FOT envelope—were used. To verify that results obtained during the three test periods were consistent, the January 1970 data was also grouped into the 1969 and 1971 formats. Using this comparison scheme, shift rates, outage rates, and distribution of frequency-hours among frequency envelopes were determined and compared.

Shift Rates

Table 3 summarizes the shift rates for each data set. To illustrate how much the shift rate can fluctuate in a short time, figure 3 shows daily shift rates for the path between the Oklahoma City and NCS Guam from 18 November through 18 December 1969. Considering the variability demonstrated in figure 3, the average shift rates shown in table 3 are surprisingly consistent for the different units within each of the three time periods sampled.

Table 4 compares shift rates within the various bands for the three data periods. Part A lists shift rates for January 1970, using the FOT-MUF band as a base for comparing the differences. The results are similar for all 3 ships.

Overall shift rates for frequencies in the LUF-FOT and FOT-MUF bands are identical. The shift rate is twice as high outside these two bands. Shift rates for the no-LUF-FOT envelope periods lie in between, which is exactly the expected result, since this region contains both a narrow FOT-MUF band of good frequencies and frequencies outside the FOT-MUF region. A breakdown of the no-envelope period shows that nearly a third of the frequency-hours fell within the narrow FOT-MUF band, and that shift rates for this region were almost identical to the remaining FOT-MUF data. Similar results were obtained when comparing the frequency-hours falling outside the FOT-MUF band with data in the outside-LUF-MUF region.

Part B of table 4 compares the reformatted January 1970 data with that from March and April 1971, again using the FOT-MUF band as a base. As expected, the shift rate outside the band is generally higher than inside. However, shift rates outside the FOT-MUF band were higher during March and April 1971 than during January 1970. This largely reflects the Oklahoma City/NCS Guam frequencies being outside the LUF-MUF envelope during 1971 more often than during 1970. Thus, the shift rate for this band was weighted more heavily, with a consequent increase in shift rate. This observation is supported by a later analysis of the distribution of frequency-hours.

TABLE 3

SHIFT RATES
(Shifts/hour)

Source (to/from)	LUF-FOT	FOT-MUF		Outside LUF-MUF	No envelope	Total
Part A: January 1970						
Oklahoma City/NCS Guam	.326	.364		.813	.503	.401
Constellation/NCS Guam	.383	.359		.849	.657	.446
Ranger/NCS Guam	.355	.347		.658	.524	.403
Overall	.358	.358		.775	.579	.420
			Outside FOT-MUF			
Part B: March, April 1971						
Oklahoma City/NCS Guam		.110	.254			.192
NCS Guam/Oklahoma City		.260	.384			.339
Overall		.169	.313			.255
			Outside LUF-FOT			
Part C: April-December 1969						
Annapolis/NCS Asmara	.134		.148		.222	.146
Oklahoma City/NCS Guam (Jul)	.179		.232		.202	.195
Oklahoma City/NCS Guam (Nov-Dec)	.113		.260		.352	.199
NCS Guam/Oklahoma City (Jul)	.117		.264		.200	.167
NCS Guam/Oklahoma City (Nov-Dec)	.136		.402		.313	.231
Overall	.133		.279		.269	.198

Part C of table 4 compares January 1970 data with data from April-December 1969. The data is grouped into three categories: LUF-FOT, outside LUF-FOT, and no-LUF-FOT envelope. The LUF-FOT band is used as the base comparison band, since MUF was not listed in DNC-14 for 1969. As in part B, the overall shift rate in the region outside the listed DNC-14 frequency band (2.10 shifts per hour) lies between the in-envelope and outside-LUF-MUF envelope computed for January 1970 alone (between 1.0 and 2.17). It is also biased toward the outside LUF-MUF band, as was the case when only the FOT-MUF band was given in 1971. It seems that when only a single DNC-14 frequency band (either FOT-MUF or LUF-FOT) is given in tabular form the shift rate outside that band approximates the shift rate observed outside both bands when both are listed for the operator to use. This shift rate, in turn, is nearly double the listed in-band shift rate. Thus, withholding the third DNC-14 parameter has eliminated an additional frequency band, a potential source of confidence for an operator, and has perhaps caused him to shift frequencies more often than necessary. There is also a possibility that DNC-14 guidelines simply formed a bias, and that once outside the listed band or bands, operators shift frequencies for no other reason than to return to the band even though a frequency may still be good.

A final comment on part C concerns the no-LUF-FOT envelope period of the April-December 1969 data. The computed shift rate of 2.02 shifts per hour is nearly equal to the outside-envelope shift rate. This should be expected, since the predicted propagation characteristics for all frequencies during the no-envelope periods are about the same as those outside the envelope for January 1970, when MUF was listed. There remains, however, a narrow FOT-MUF band during a no-LUF-FOT envelope period. That band reduces the shift rate to a point between the in-band and

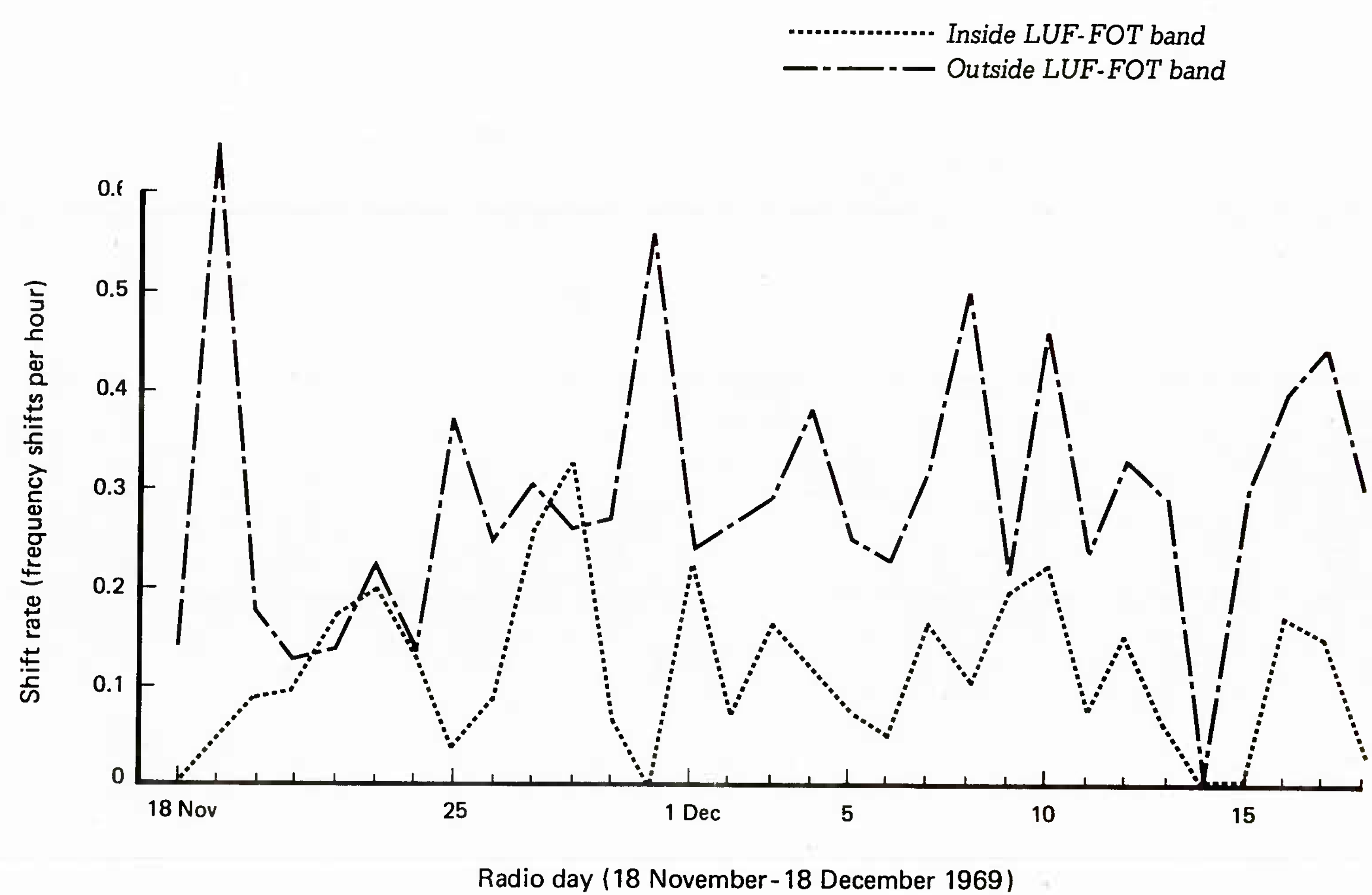


FIG. 3: DAILY SHIFT RATES FOR FULL-PERIOD TERMINATION FROM NCS GUAM TO USS OKLAHOMA CITY

TABLE 4

COMPARISON OF SHIFT RATES DURING DIFFERENT SAMPLING PERIODS

Part A: January 1970 alone		Base band rate ÷ FOT-MUF rate		
Source (to/from)	LUF-FOT	FOT-MUF	Outside LUF-MUF	No-LUF-FOT envelope
Oklahoma City/Guam	.90	1.0	2.23	1.38
Constellation/Guam	1.07	1.0	2.36	1.83
Ranger/Guam	1.02	1.0	1.90	1.51
Overall	1.0	1.0	2.17	1.62

Part B: January 1970 and March-April 1971	Base band rate ÷ FOT-MUF rate	
Source (to/from)	FOT-MUF	Outside FOT-MUF
Oklahoma City/Guam	1.0	1.16
Constellation/Guam	1.0	1.40
Ranger/Guam	1.0	1.23
Overall		1.28
Oklahoma City/Guam	1.0	2.30
Guam/Oklahoma City	1.0	1.48
Overall		1.85

Part C: January 1970 and April-December 1969	Base band rate ÷ LUF-FOT rate		
Source (to/from)	LUF-FOT	Outside LUF-FOT	No-LUF-FOT envelope
Oklahoma City/Guam	1.0	1.42	1.55
Constellation/Guam	1.0	1.24	1.71
Ranger/Guam	1.0	1.25	1.48
Overall		1.30	1.62
Annapolis/Guam	1.0	1.10	1.66
Oklahoma City (Jul)/Guam	1.0	1.30	1.13
Oklahoma City (Nov-Dec)/Guam	1.0	2.30	3.10
Guam/Oklahoma City (Nov-Dec)	1.0	2.26	1.71
Guam/Oklahoma City (Nov-Dec)	1.0	2.96	2.30
Overall		2.10	2.02

outside-band shift rates. Thus, listing a second DNC-14 band again seems to lower the shift rate over that observed when the band is not listed.

Two additional observations can be made independent of the DNC-14 comparisons concerning the shift rate calculations shown in table 3:

- For two of the three cases involving Oklahoma City and NCS Guam the ship/shore shift rate is higher (by 65 percent during March-April 1971 and by 15 percent during November-December 1969); in one case, it is lower (by 12 percent during July 1969) than the corresponding shore/ship shift rate. Higher shift rates on paths that are theoretically identical are not surprising, because of the less-powerful transmitting equipment generally found aboard ship.

● During January 1970, the 3 ships reporting were all on Yankee Station and competing for similar frequencies. The shift rate is twice as high as that observed during other test periods, when each ship was not in a "fixed" location but transiting through areas relatively free from competition for frequency use from other users of the same CommSta (NCS Guam). This result indicates that the overall shift rate is higher when the density of subscribers in a given region is greater and that shift rates are higher on ship-to-shore paths.

Outage Rates

Outage rates for each data set were computed and compared using the same scheme as that for the shift rate analysis. Table 5 lists outage rates by data source; table 6 compares outage rates obtained for the three different sampling periods.

TABLE 5

OUTAGE RATES

Source (to/from)	LUF-FOT	FOT-MUF	Outside LUF-MUF	No envelope	Total
Part A: January 1970					
Oklahoma City/NCS Guam	.074	.053	.093	.20	.074
Constellation/NCS Guam	.085	.080	.157	.40	.107
Ranger/NCS Guam	.084	.067	.139	.384	.099
Overall	.082	.069	.136	.34	.095
			Outside FOT-MUF		
Part B: March, April 1971					
Oklahoma City/NCS Guam		.054	.041		.046
NCS Guam/Oklahoma City		.078	.055		.063
Overall		.063	.047		.054
			Outside LUF-FOT		
Part C: April-December 1969					
Annapolis/NCS Asmara	.063		.072	.328	.082
Oklahoma City/NCS Guam (Jul)	.010		.010	.019	.011
Oklahoma City/NCS Guam (Nov-Dec)	.016		.017	.130	.027
NCS Guam/Oklahoma City (Jul)	.045		.038	.082	.049
NCS Guam/Oklahoma City (Nov-Dec)	.037		.055	.281	.065
Overall	.031		.036	.146	.045

These values are almost as consistent as the shift rates and, except for the outage rate comparison in part B of table 6, indicate similar performance trends. More specifically, in half the cases in table 5, the outage rates for frequencies copied outside the given DNC-14 bands are higher than those for frequencies copied within the envelope. Copying frequencies outside the given envelopes can thus degrade circuit continuity, but not always. Also, the outage rates during "no-LUF-FOT envelope" periods were consistently much greater than those when an envelope existed. This is the kind of result expected under the hypothesis that DNC-14 predictions are reasonably accurate in isolating good frequencies. When a frequency outside the envelope is copied

and many frequencies are propagating well, outages can be minimized by shifting. During no-envelope periods, however, practically no frequencies are expected to be good, so fewer alternatives exist when an outage occurs.

TABLE 6

COMPARISON OF OUTAGE RATES DURING DIFFERENT SAMPLING PERIODS

Part A: January 1970 alone			Base band rate ÷ FOT-MUF rate	
Source (to/from)	LUF-FOT	FOT-MUF	Outside LUF-MUF	No-LUF-FOT envelope
Oklahoma City/Guam	1.40	1.0	1.75	3.58
Constellation/Guam	1.06	1.0	1.96	5.0
Ranger/Guam	1.25	1.0	2.07	5.7
Overall	1.19		1.97	4.93

Part B: January 1970 and March-April 1971		Base band rate ÷ FOT-MUF rate
Source (to/from)	FOT-MUF	Outside FOT-MUF
Oklahoma City/Guam	1.0	1.41
Constellation/Guam	1.0	1.28
Ranger/Guam	1.0	1.40
Overall		1.33
Oklahoma City/Guam	1.0	.76
Guam/Oklahoma City	1.0	.71
Overall		.74

Part C: January 1970 and April-December 1969			Base band rate ÷ LUF-FOT rate
Source (to/from)	LUF-FOT	Outside LUF-FOT	No-LUF-FOT envelope
Oklahoma City/Guam	1.0	.84	2.70
Constellation/Guam	1.0	1.15	4.70
Ranger/Guam	1.0	1.07	4.60
Overall		1.05	4.15
Annapolis/Guam	1.0	1.14	5.2
Oklahoma City (Jul)/Guam	1.0	1.0	1.9
Oklahoma City (Nov-Dec)/Guam	1.0	1.06	8.1
Guam/Oklahoma City (Jul)	1.0	.84	1.8
Guam/Oklahoma City (Nov-Dec)	1.0	1.49	7.6
Overall		1.16	4.71

Table 6, part A, shows that outage rates are least within the FOT-MUF band for all 3 ships, and next to least in the LUF-FOT band. The average LUF-FOT outage rate (all sources combined) is 1.19 using the FOT-MUF band as the base, while the individual and average total outage rate outside the LUF-MUF envelope is about twice the FOT-MUF figure. Outages during no-LUF-MUF envelope periods average nearly five times as high.

A comparison of January 1970 outage rates with those for April-December 1969 (part C) shows remarkably similar results. Using the LUF-FOT band as the base, outage rates outside this

band (excluding no-envelope periods) are slightly greater than within the LUF-FOT band. And the no-envelope period shows a much larger outage rate—four to five times that within the DNC-14 band. Thus, the contention that using DNC-14 enhances circuit continuity is again supported. Suppression of the FOT-MUF band, however, tends to obscure the fact that good frequencies in this region are primarily responsible for the comparable values for the outage rates within and outside the LUF-FOT band.

But the relatively good agreement between shift and outage rates within the same and different time frames is not found when outage rate data from March-April 1971 is compared with that from January 1970 (part B). An apparent disagreement is the doubling of overall outage rates for the region outside the FOT-MUF band—0.74 for March-April 1971 compared with 1.33 for January 1970. Nearly all data sources from 1969 and 1970 give outage results—either direct or implied—showing that outage rates within the FOT-MUF band tend to be less than those within the LUF-FOT band, with a ratio of about 1.2. When the FOT-MUF band is compared with the region outside the LUF-MUF envelope, the ratio is closer to 2, and approaches 5 when compared with no-envelope periods.

The explanation (see the next section) for this apparent inconsistency is that frequencies above MUF during this period accounted for nearly 25 percent of the total frequency-hours and had an outage rate about half that found within the FOT-MUF band; meanwhile, the outage rate for frequencies below FOT was the same as that in the FOT-MUF band. MUF was thus of little value in this particular case. In fact, it may have been misleading.

In terms of user density effects on outage rates and differences in those rates between ship/shore and shore/ship circuits, the results (table 6) are similar to those noted for shift rates:

- All three instances where data was available on send and receive sides of a single termination showed greater outage rates—from 50 to 250 percent—for the ship's send path. This complements the assumption made in the shift rate analysis that less-powerful transmitters, and possibly less ability to maintain equipment aboard a ship, degrade circuit performance.

- The average outage rate during January 1970 was nearly twice that during 1969 and 1971 for ships at about the same ranges from NCS Guam. Thus, competition among ships for good frequencies seems to have also increased outage rates in this case. The only exception is the high outage rate observed for the Annapolis. That ship, however, was transiting the Indian Ocean during April-May 1969 about 3000 miles from NCS Asmara (reference 2), a distance much greater than in the other cases.

Distribution of Frequency-Hours

The analysis of performance indexes shows some evidence that frequencies copied outside the DNC-14 envelope may sometimes show superior propagation characteristics. Another way of examining such effects is to determine how much time is spent inside and outside the DNC-14 bands, and which regions outside these bands (above MUF and below LUF) exhibited improved propagation. Such distributions also can be used to examine whether presentation of either a LUF-FOT or MUF-FOT table by itself biases the selection of frequencies, and whether the DNC-14-predicted LUF-MUF envelope is accurate enough to serve as a guideline for allocating frequencies in an area.

Table 7 shows such distributions by listing the proportion of time that frequencies were copied within the several regions defined by the DNC-14 parameters. As with the analysis of shift and outage rates, results from the three data periods are compared in table 8.

TABLE 7

PROPORTION OF TIME FREQUENCIES WERE COPIED WITHIN AND OUTSIDE DNC-14 BANDS

Source (to/from)	LUF-FOT	FOT-MUF		Outside LUF-MUF	No-LUF-MUF envelope
Part A: January 1970					
Oklahoma City/NCS Guam	46.3	39.4		10.8	4.5
Constellation/NCS Guam	40.7	41.7		12.9	4.8
Ranger/NCS Guam	50.3	31.3		14.5	3.9
Overall	45.1	37.7		12.8	4.4
			Outside FOT-MUF		
Part B: March, April 1971					
Oklahoma City/NCS Guam		43.0	57.0		
NCS Guam/Oklahoma City		36.7	63.3		
Overall		40.3	59.7		
			Outside LUF-FOT		
Part C: April-December 1969					
Annapolis/NCS Asmara	47.2		49.2		4.5
Oklahoma City/NCS Guam (Jul)	60.5		23.9		15.6
Oklahoma City/NCS Guam (Nov-Dec)	46.9		44.2		8.9
NCS Guam/Oklahoma City (Jul)	59.2		25.3		15.5
NCS Guam/Oklahoma City (Nov-Dec)	61.1		29.6		9.3
Overall	55.1		34.2		10.7

Part A of table 7 shows that for the 3 ships taking part in the January 1970 test, the average proportion of time spent outside the given LUF-MUF band was 12.8 percent. Results for each ship varied only slightly from this average. The average time spent within the LUF-FOT band was 45.1 percent, compared with 37.7 percent within the FOT-MUF band, a ratio of 1.2 to 1. This ratio appears in table 8, part A.

Figure 4 diagrams the results appearing in table 7, showing the different frequency bands and the overall percentage of time spent in each. The outside LUF-MUF region in figure 4 is also separated into frequency-hours spent above MUF and below LUF. The no-LUF-FOT envelope period is considered separately by adjusting the percentage of frequency-hours spent within and below the remaining FOT-MUF band. Percentages not including the no-envelope period are also listed for the various bands. The combination of figure 4 and tables 7 and 8 therefore gives a rather complete picture of the relative amount of time spent in the frequency bands.

Part C of table 8 shows the difference between April-December 1969 and January 1970 data. In all the 1970 cases and in two of the five 1969 cases, ships spent as much or a little more time outside as within the LUF-FOT band. In the other three 1969 cases, however, they spent less than half as much time outside the band as inside. This type of behavior is not present in the FOT-MUF

data of part B, which is quite consistent. Thus, results appear to be rather unpredictable when only LUF and FOT data is listed in DNC-14, perhaps indicating that the LUF-FOT band is more sensitive to changes in propagation conditions. When considered in light of the previous results showing that lower outage and shift rates occurred for frequencies in the FOT-MUF band than for those in the LUF-FOT band, this sensitivity indicates that the change in DNC-14 format to list the FOT-MUF band (see appendix B) was a reasonable one.

TABLE 8

COMPARISON OF FREQUENCY-HOUR DISTRIBUTION WITHIN DNC-14 BANDS FOR DIFFERENT SAMPLING PERIODS

Part A: January 1970 alone			Base band ÷ FOT-MUF	
Source (to/from)	LUF-FOT	FOT-MUF	Outside LUF-MUF	No-LUF-FOT envelope
Oklahoma City/Guam	1.21	1.0	.28	.12
Constellation/Guam	.98	1.0	.31	.11
Ranger/Guam	1.61	1.0	.46	.12
Overall	1.20		.34	.117

Part B: January 1970 and March-April 1971		Base band ÷ FOT-MUF
Source (to/from)	FOT-MUF	Outside FOT-MUF
Oklahoma City/Guam	1.0	1.51
Constellation/Guam	1.0	1.31
Ranger/Guam	1.0	2.02
Overall		1.55
Oklahoma City/Guam	1.0	1.32
Guam/Oklahoma City	1.0	1.72
Overall		1.48

Part C: January 1970 and April-December 1969		Base band ÷ LUF-FOT	
Source (to/from)	LUF-FOT	Outside LUF-FOT	No-LUF-FOT envelope
Oklahoma City/Guam	1.0	1.06	.10
Constellation/Guam	1.0	1.34	.12
Ranger/Guam	1.0	.91	.08
Overall		1.12	.10
Annapolis/Guam	1.0	1.0	.12
Oklahoma City/Guam	1.0	.40	.26
Oklahoma City/Guam	1.0	.94	.19
Guam/Oklahoma City	1.0	.43	.26
Guam/Oklahoma City	1.0	.48	.15
Overall		.62	.19

Finally, figure 4 shows the proportion of time spent above and below FOT. When all three DNC-14 parameters were available, operators spent about as much time above FOT as below. When only two parameters were listed, there was a bias of 10 percent or more toward MUF or LUF. Thus, there seems to be a frequency-selection bias that depends on the DNC-14 parameters made available to an operator. The bias under the present DNC-14 format is, however, probably beneficial, since shift and outage rates are lower in the FOT-MUF band than in the LUF-FOT band.

	a) Excluding no LUF-FOT periods	a) No LUF-FOT envelope	a) Total	b)	c) Excluding no LUF-FOT periods	c) No LUF-FOT envelope	c) Total
Above MUF	6.7%	31.8%	7.8%	20.0%			
MUF – FOT	39.4%	36.4%	39.3%	40.3%	29.3%	65.4%	33.2%
FOT – LUF	47.2%	31.8%	45.1	39.7%	61.7%	34.6%	55.1%
Below LUF	6.7%		7.8%		9.0%		11.7%

a) January 1970 b) March, April 1971 c) April-December 1969

FIG. 4: DISTRIBUTION OF FREQUENCY-HOURS WITHIN DNC-14-DEFINED REGIONS

Distribution of Frequency Shifts

Figure 4 also gives some information on the variation in time spent copying frequencies above MUF and below LUF. Many operators assume that MUF and LUF should be sharp cutoffs above and below which good frequencies are rarely found, and that a change in the DNC-14 envelope should bring about a frequency fade when a frequency is being copied close to the envelope boundary. But the parameter definitions (appendix B) and the way DNC-14 instructions indicate they are to be used are not so clear-cut. For example, the maximum observed frequency should be above the predicted MUF half of any month. But this does not exclude the possible contribution of DNC-14 in predicting daily changes in propagation conditions, thereby alerting the operator to the possibility that a frequency in use will begin to deteriorate.

To show this characteristic of DNC-14 predictions, figure 5 shows the distribution of frequency-hours with respect to MUF for the 1970 data set, where the percentage of time that frequencies outside the LUF-MUF envelope were copied was a minimum. Figure 6 displays a similar graph for the data sets when this percentage was a maximum.

Figure 4 shows that the variation below LUF was not very great among the three sampling periods, while the amount of time above MUF seemed to vary significantly—from 7.8 to 20 percent. The band from 3 to 5 MHz below MUF, corresponding to the average location of FOT with respect to MUF, was the most frequently used region for the January 1970 data. For the Newport/Key West and 1971 data, the distribution peak lies from 1 to 2 MHz below MUF, while DNC-14 lists the FOT-MUF band to be nearly 4 to 6 MHz wide. This indicates that MUF for these cases was probably lower than the actual cutoff. In either case, though, the preponderance of frequencies copied lay generally in the regions predicted to be good by DNC-14.

To examine frequency fading in a region about MUF, frequency shifts were recorded for frequencies as they approached MUF; see figure 7.[1] As expected, the data (for March-April 1971) shows that frequencies were copied a significant amount of the time for 2 to 6 hours after they went above MUF.

Figure 8 displays shift data for all three parameters during January 1970, which is the only period all three were available. Again, only those shifts were considered where a frequency was approaching a particular parameter curve. The agreement with DNC-14 predictions shown in the figure is rather good. A majority of frequencies approaching FOT pass into the FOT-MUF region. All frequencies are shifted within 2 hours after crossing MUF, with 60 percent of the frequency shifts occuring within an hour of MUF. Normally, a frequency approaches LUF only during the evening transition period, when the rate of change in LUF is rather high and frequencies deteriorate rapidly. In the cases shown, 92 percent of all shifts occurred within 2 hours of LUF, with nearly equal division of the shifts above and below.

These results indicate generally that DNC-14 is a relatively good predictor of diurnal variations in frequency propagation and can, therefore, contribute to circuit quality when used this way.

[1] A number of shifts occurred at the same time the frequency equaled MUF. Rather than assign half of them to +1 and half to −1 hour, they are shown separately as dips in the graph at 0 hour.

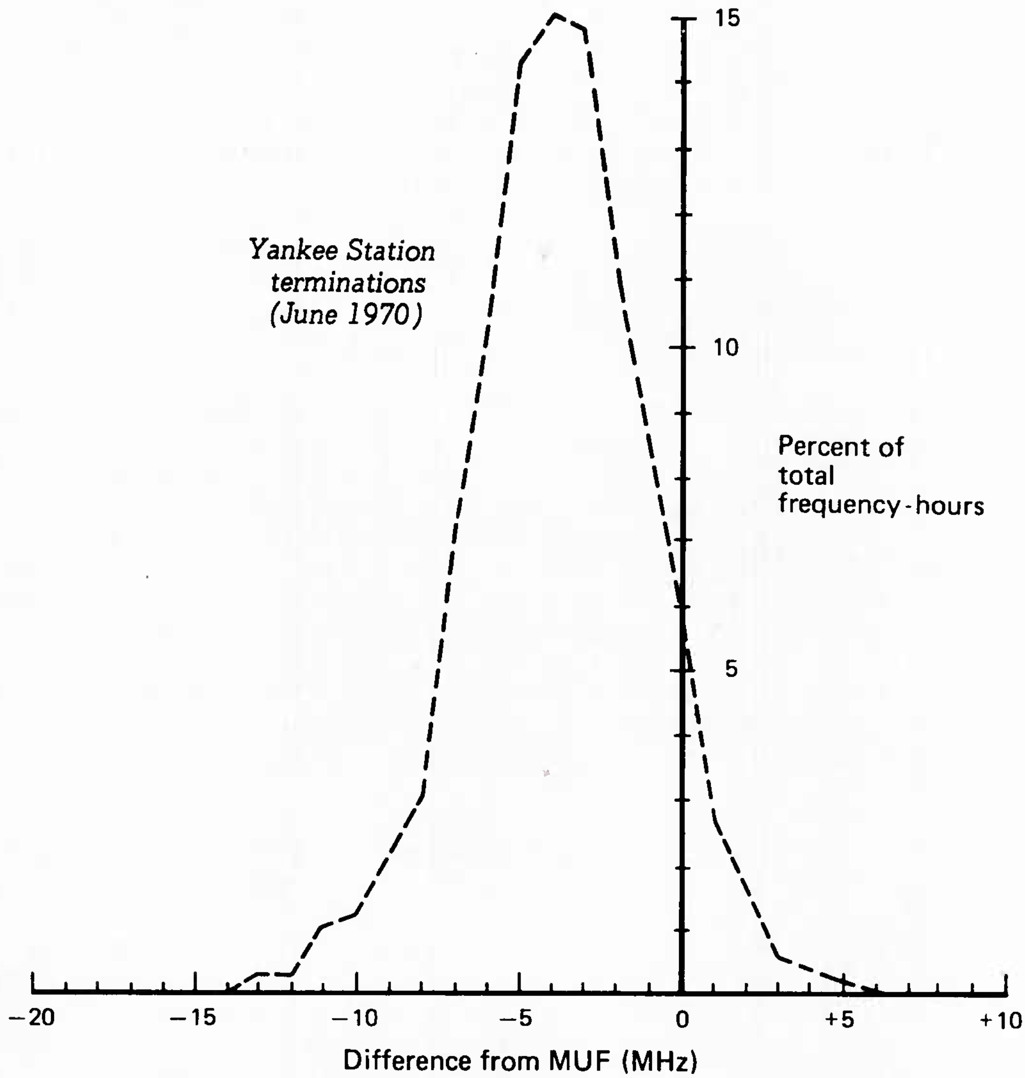


FIG. 5: DISTRIBUTION OF FREQUENCY-HOURS ABOUT MUF

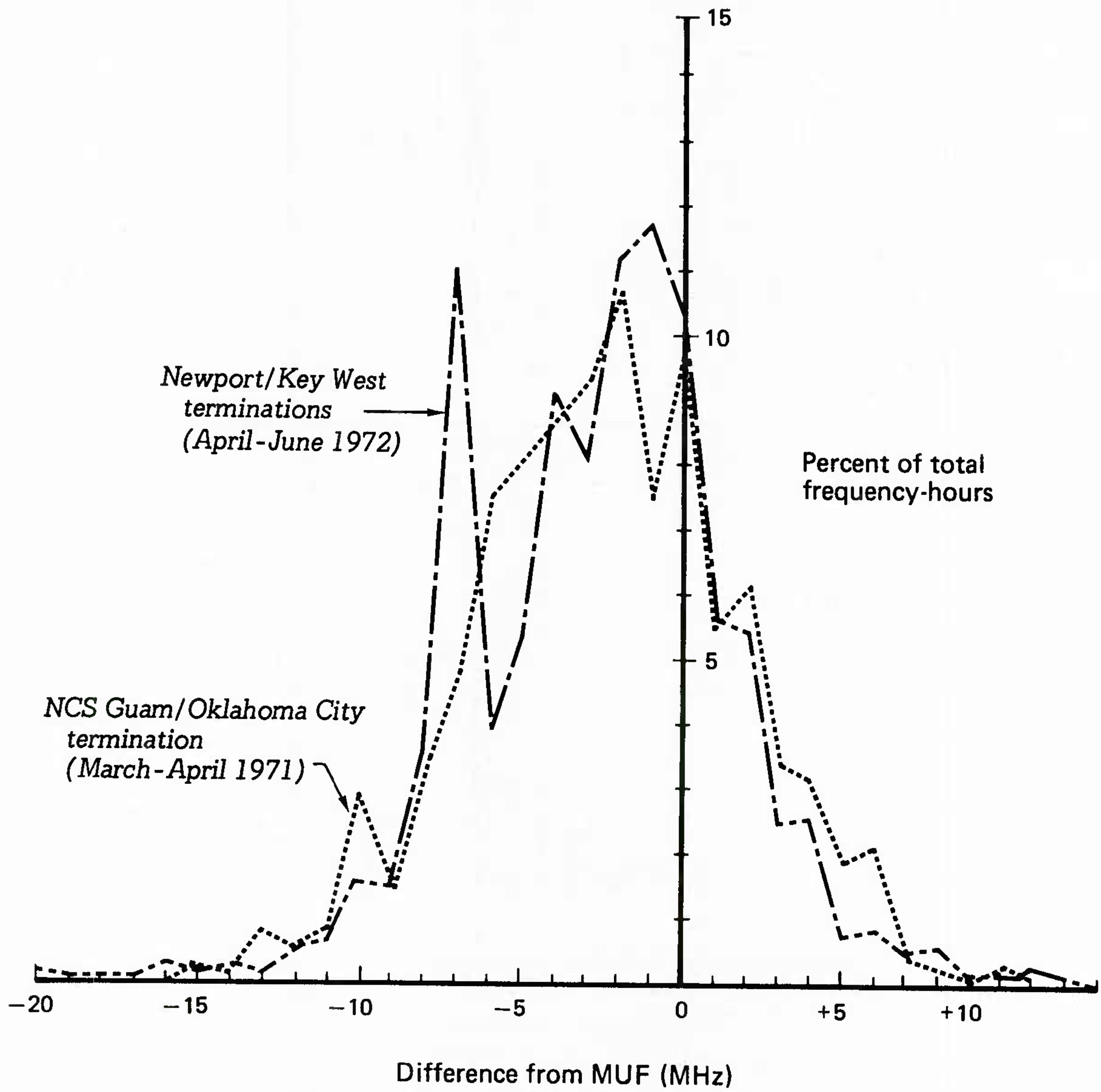
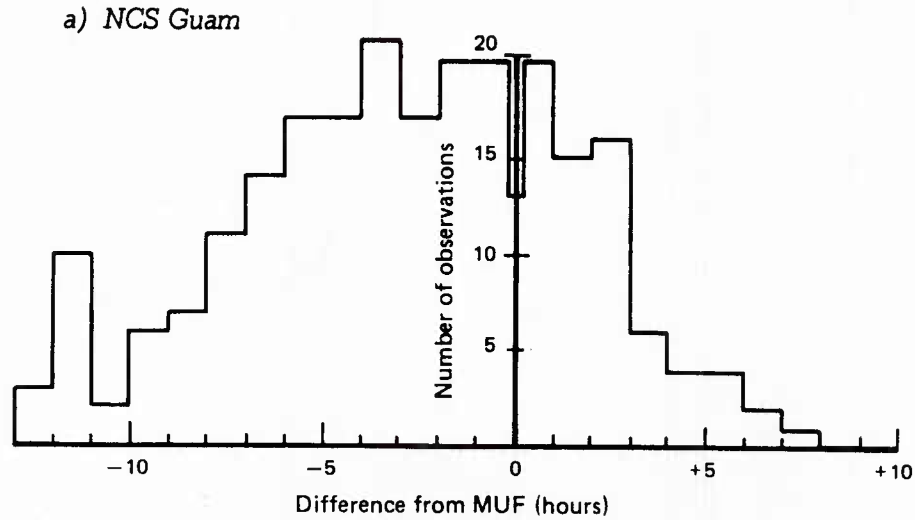


FIG. 6: DISTRIBUTION OF FREQUENCY-HOURS ABOUT MUF



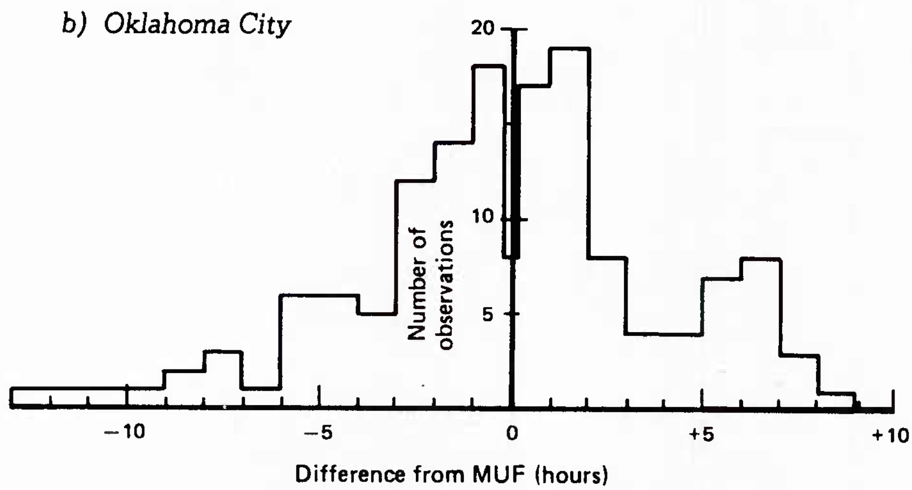


FIG. 7: DISTRIBUTION OF TIMES OF FREQUENCY SHIFTS WHEN APPROACHING MUF

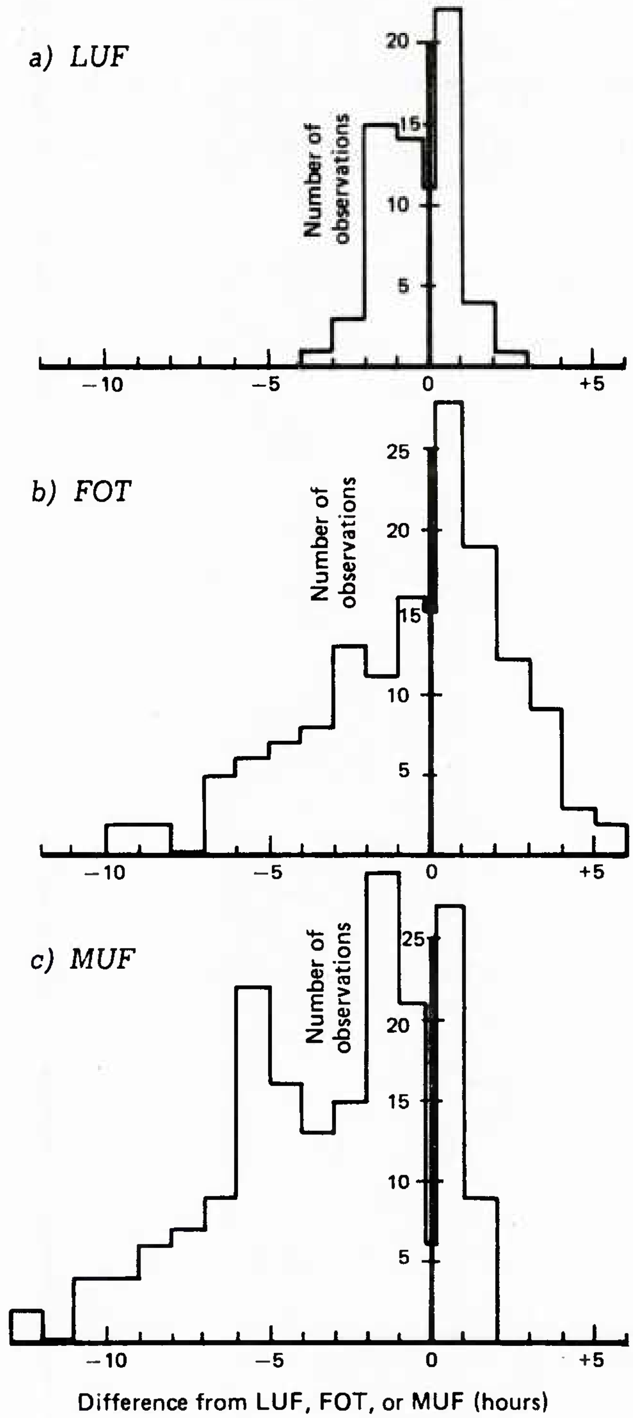


FIG. 8: DISTRIBUTION OF TIMES OF FREQUENCY SHIFTS WHEN APPROACHING LUF, FOT, AND MUF (OKLAHOMA CITY)

REFERENCES

1. DNC-14, "Recommended Frequency Bands and Guide," Unclassified, 1973

2. CNA Research Contribution 261, "Communication in the Indian Ocean; Transit of the USS Annapolis (U)," Confidential, Apr 1974

APPENDIX A

OPERATING AREAS

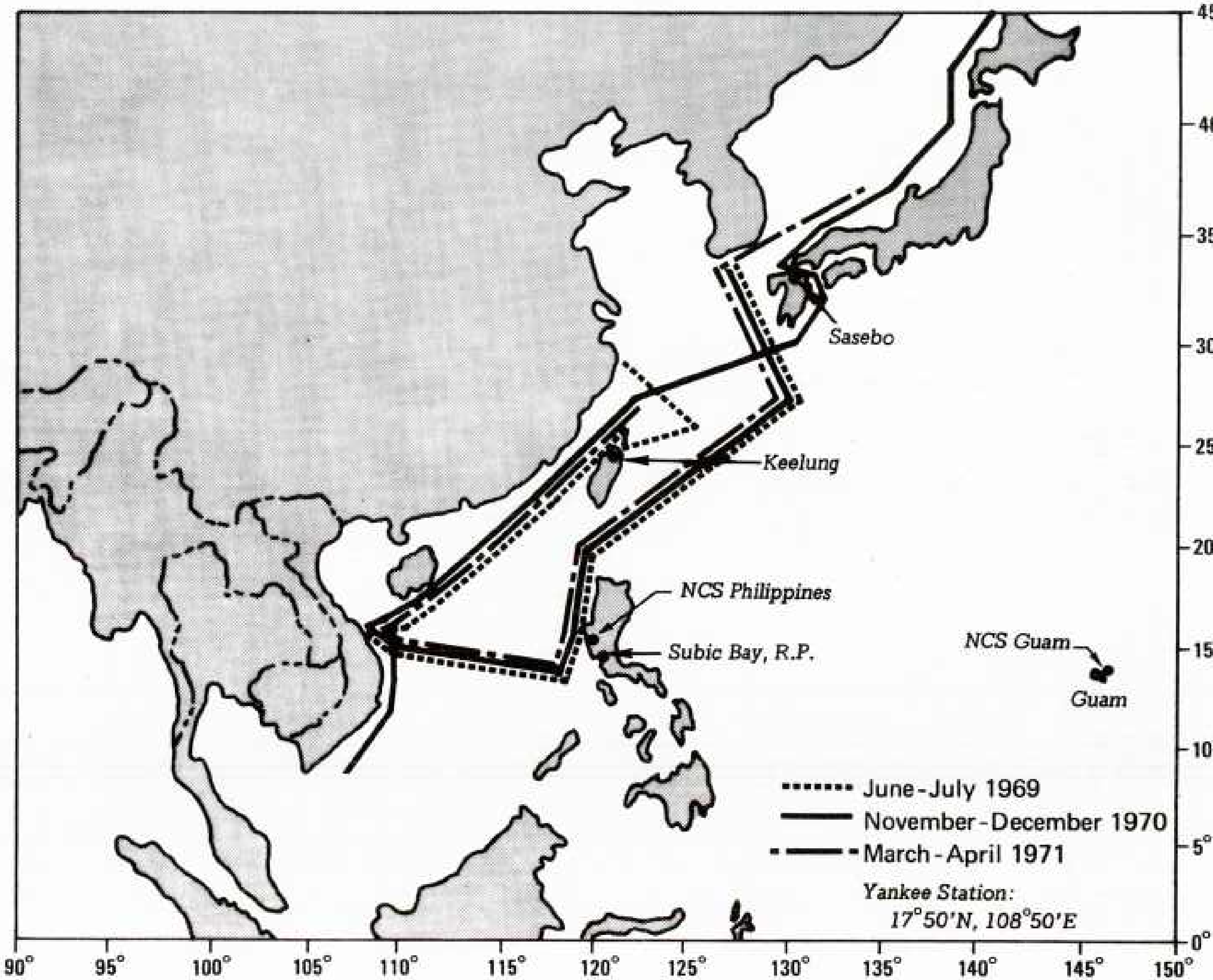


FIG. A-1: USS OKLAHOMA CITY TRANSIT PATHS

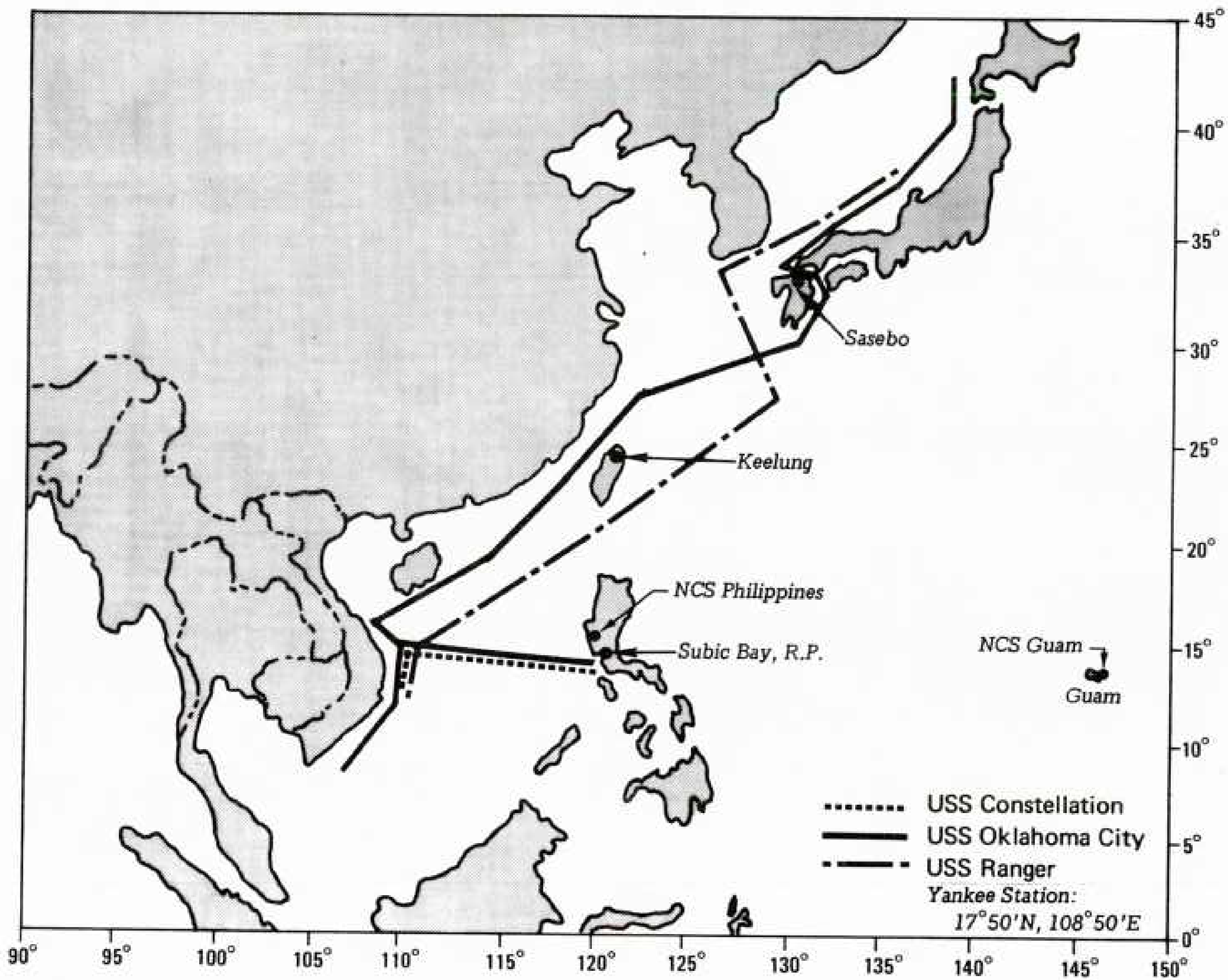


FIG. A-2: TRANSIT PATHS FOR JANUARY 1970 DATA

APPENDIX B

DNC-14 (1969-1972)

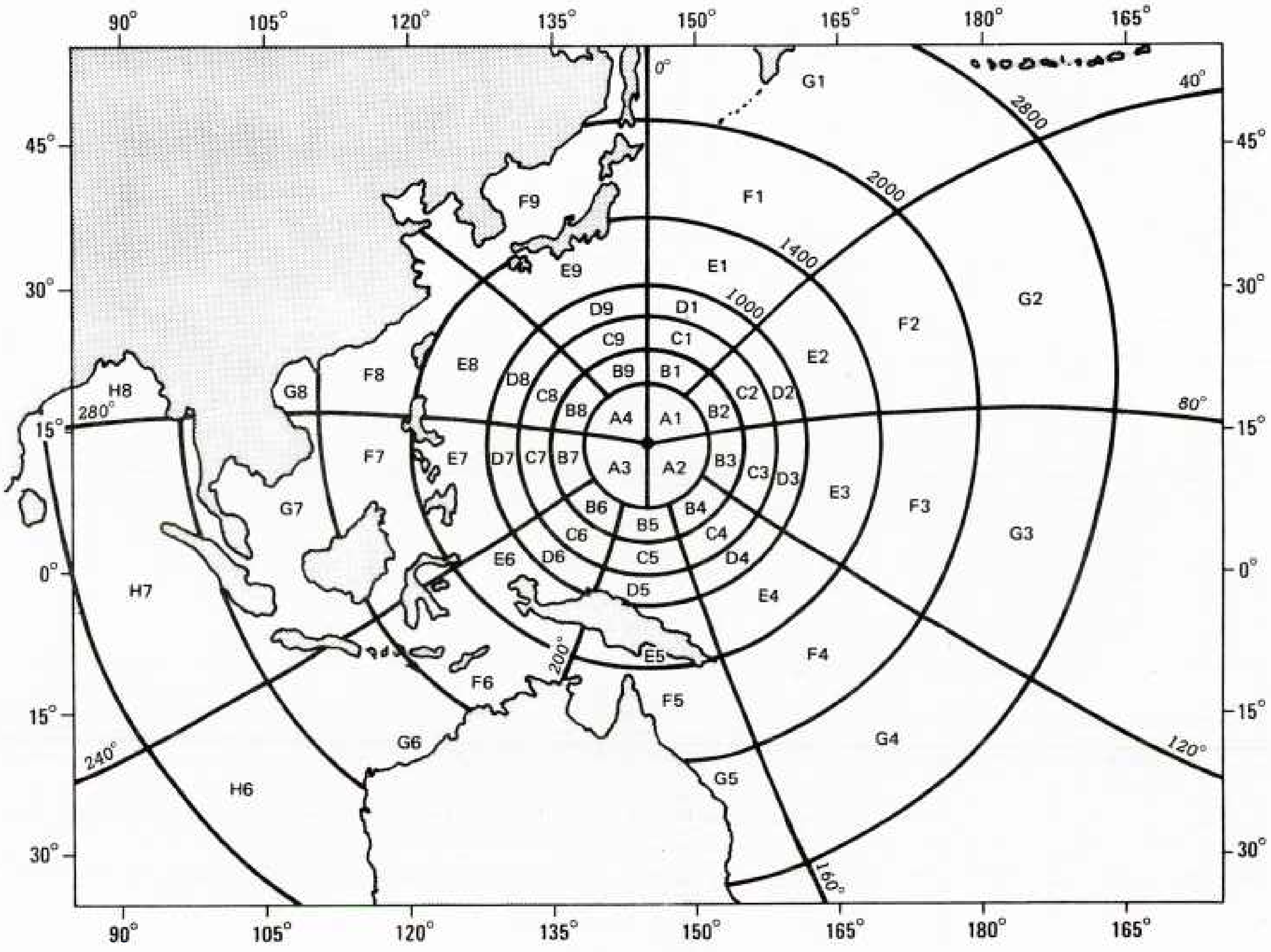
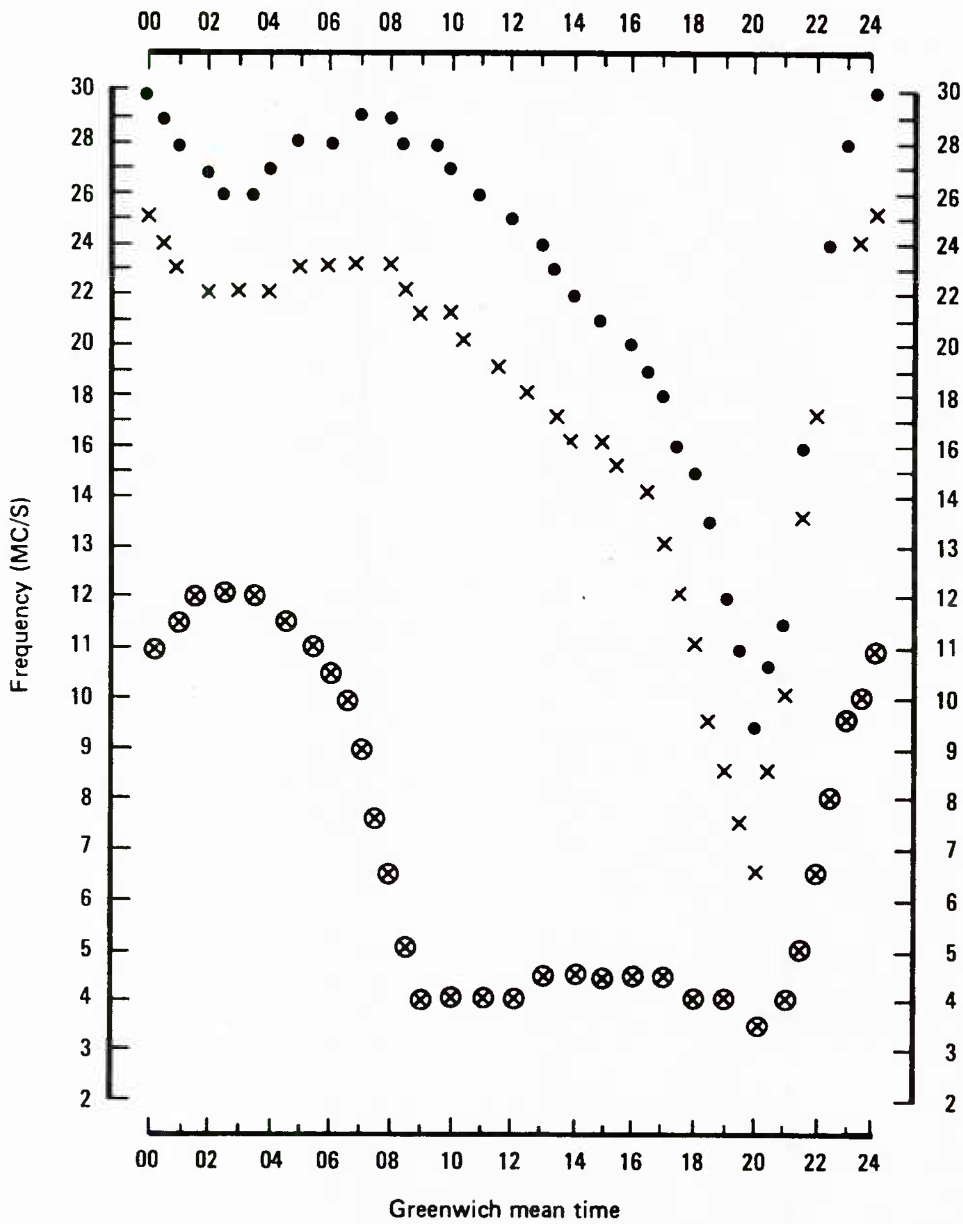


FIG. B-1: DNC-14 FREQUENCY PREDICTION SECTORS FOR NCS GUAM

JAN SSN = 94. E 30.013

E8	*to*	*Guam*	*Azimuths*	*N. miles*
23.17N – 124.03E		13.29N – 144.40E	113.5 300.0	1301.2



GMT	MUF	FOT	LUF
1	28.8	23.9	
2	27.0	22.6	12.4
3	26.0	22.1	
4	27.4	22.6	12.1
5	28.0	23.0	
6	28.3	23.5	10.8
7	29.1	23.9	
8	29.1	23.9	6.7
9	28.0	21.7	
10	26.6	21.1	4.1
11	25.9	20.3	
12	25.0	19.5	4.1
13	24.0	18.1	
14	22.0	17.0	4.7
15	20.9	16.0	
16	20.0	15.3	4.7
17	17.8	13.1	
18	14.9	11.0	4.4
19	12.3	8.8	
20	9.9	7.0	3.8
21	11.7	10.0	
22	20.0	17.2	6.7
23	28.1	24.1	
24	29.8	25.8	11.1

Key:

- ● MUF
- × FOT
- ⊗ LUF

FIG. B-2: DNC-14 COMPUTER OUTPUT